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Summary of Key Research Findings about Underwater Noise and Vessel Disturbance

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Summary of Key Research Findings about Underwater Noise and Vessel Disturbance

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I. Executive Summary

The Washington State Legislature passed SB 5577 in Spring 2019, directing the Washington Department of Fish and Wildlife (WDFW) to develop rules for a new commercial whale-watching licensing program. As part of this process, WDFW asked the Washington State Academy of Sciences (WSAS) to conduct a scientific and technical review of the best available science to inform the development of new WDFW regulations for a commercial whale watching licensing program in Washington State.

The WSAS Committee on Underwater Acoustics and Disturbance, hereafter referred to as "the committee", has prepared this summary of the research on disturbance and noise impacts to Southern Resident Killer Whales (SRKW) from small vessels and commercial whale watching.

The committee interpreted the scope of this work to include expanding upon the literature pertaining to vessels referenced by the Orca Task Force and Vessels Working Group, as well as highlighting the assumptions in key studies and how they inform the interpretation of data for use in management.

Determining impacts of whale watching vessels is complicated by the scope and context of many studies to date, including study age (and hence vessel management regime), sample size, and other limitations, and the confounding effects of an array of different threats including limited prey availability, polluted waters, and small population size. As a result, many of the questions surrounding vessel disturbance of SRKW cannot be answered with certainty.

Given the fragile condition of the SRKW population, however, the committee considers the precautionary approach to management of known stressors to be justified. The committee recommends defining every interaction with an SRKW as an opportunity to disturb a whale.

A summary of the Relevant Scientific Findings is as follows:

1. Close approaches by vessels can cause significant direct effects on foraging.
2. Close approaches of boats can cause indirect negative effects including masking (elevated noise levels that interfere with communication and foraging), even with slow-moving vessels.
3. Behavioral responses to noise and disturbance, such as increased surface-active behaviors or changes in vocalizations, can increase energy expenditure.
4. Reduced individual foraging success due to vessels may in turn result in reduced survival and fecundity that may result in population-level effects.
5. Chinook prey abundance has a greater effect on SRKW population growth rates than vessel noise and disturbance, according to recent population viability analysis models.
6. Strike risk is not zero, and the risk of injury and or mortality increases with vessel speed.
7. Data gaps include an understanding of the chronic effects of whale watching activities on SRKW foraging success under current management, and of the extent that reduced foraging success translates into the growth or decline for the SRKW population.

Additional findings specifically pertaining to Mitigation and Management are as follows:

8. While the presence of SRKW in inshore waters over recent years has been lower than historically observed, the evidence does not suggest basing management solely on recent levels of inshore habitat use.
9. Observed habitat of SRKW suggests extending management actions to the entire SRKW home range, including the Salish Sea and outer coasts of Washington and southern Vancouver Island.
10. There is insufficient evidence for a positive "sentinel" effect of commercial whale watching; this topic needs further study.

11. Slowing boats and decreasing time around whales, as well as increasing distance from whales, are considered the primary means to reduce noise levels.
12. Reliable indicators for short-term adaptive management are not currently available. Time spent foraging, body condition, and other health indicators, such as physiological parameters, may be useful across longer time periods.

Relevant references and the committee's assessment of the scientific evidence for these findings are provided in the body of this report.

II. Interpretation of the Charge

The Washington State Academy of Sciences (WSAS) Committee on Underwater Acoustics and Disturbance has prepared this summary of research on disturbance and noise impacts to Southern Resident Killer Whales (SRKW) from small vessels and commercial whale watching.

This committee's review fits into the larger context of activities to address issues faced by the SRKW population. In 2018, the Washington State Governor established a task force including representatives from the government, private businesses, and nonprofits, to develop long-term action recommendations for orca recovery. As vessels were identified as one of the threats facing SRKW, a Vessels Working Group was also formed to consider that threat. Concurrently, the Washington State Legislature passed SB 5577 in Spring 2019, which directed the Washington Department of Fish and Wildlife (WDFW) to develop rules for a new commercial whale-watching licensing program. As part of the process, WDFW asked WSAS to conduct a scientific and technical review of the best available science to inform the development of new WDFW regulations for a commercial whale watching licensing program in Washington State.

> *"Before January 1, 2021, the department shall convene an independent panel of scientists to review the current body of best available science regarding impacts to southern resident orcas by small vessels and commercial whale watching due to disturbance and noise. The department must use the best available science in the establishment of the southern resident orca whale watching rules and continue to adaptively manage the program using the most current and best available science."*

The scope of this document is to summarize the research on potential impacts on SRKW from small vessels and commercial whale watching, including underwater noise, disturbance from the presence, density, and activities of whale watching vessels, as well as relevant findings from the broader research on whale watching impacts, underwater acoustics, and cetaceans. The committee has interpreted this scope to include carefully reviewing and expanding upon the literature pertaining to vessels referenced by the Orca Task Force and Vessels Working Group, as well as highlighting the assumptions in key studies and how they inform the interpretation of data for use in management.

The committee examined the body of peer-reviewed literature and non-formally reviewed reports (Bibliography and Appendix*)*, reporting on the caveats, limitations, and uncertainties of existing key data and knowledge that relate to SRKW. In its review, the committee also aimed to address the applicability of this science in the current context, with a focus on answering specific questions from WDFW's rule-making advisory committee and which arose in the rule proposals, and describing how current evidence can be interpreted to inform near-term policy development. Subsequent work by the committee later this year will advise on how research and data can inform changes in proposed rules through adaptive management.

III. Summary of Relevant Scientific Findings

For decades, scientists have sought to understand how underwater noise and other disturbances from boats might change the behavior or physiology of marine mammals—and thereby, potentially undermine their health, condition, and population status. In the case of the endangered SRKW, determining the impacts of whale watching vessels is complicated by the scope and context of many studies to date, including study age (and hence vessel management regime), sample size, or other limitations, and an array of different threats including limited prey availability, polluted waters and small population size.

Specifically, the waters within the Salish Sea represent a small portion of the SRKW habitat, whale watching boats are a small fraction of the noisy vessels that pass in the whales' vicinity, and vessel disturbances are just one factor among many that threaten the SRKW's survival. Whale watching guidelines have also changed appreciably over recent years. As a result, many of the questions surrounding vessel disturbance of SRKW cannot be answered with certainty.

Given the fragile condition of the SRKW population, however, the committee considers the precautionary approach to management of known stressors to be justified. According to the principle, when an activity threatens harm then measures should be taken—even if certain cause-and-effect relationships are not fully established scientifically. The committee suggests defining every interaction with an SRKW as an opportunity to disturb a whale. Table 1 summarizes critical findings made by the committee, along with caveats and considerations. Further details follow in the document.

Table 1. Summary of relevant scientific findings, along with caveats and considerations.

Critical Findings	Caveats and Considerations
Threats to SRKW	
1. Close approaches by boats can cause significant direct effects on foraging [Lusseau et al 2009].	- Most published studies on vessel effects use data collected when older whale watch guidelines with looser restrictions were in effect *(see "Vessel Behavior" below)*. No published studies have empirically assessed conditions under current whale watching guidelines. - Few studies are able to partition noise effects from physical-proximity effects.
2. Close approaches of boats can cause indirect negative effects including masking and increased production of sound [Holt et al 2008].	- "Masking" means elevated noise levels that interfere with communication and foraging. - Masking effects have been predicted to extend beyond 400 meters, even with slow-moving vessels [Wladichuk et al 2019]. - The value of compensatory behaviors is uncertain.
3. Behavioral responses to noise and disturbance, such as increased surface-active behaviors or changes in sound generation [Holt et al 2008, 2009, Noren et al 2009], can increase energy expenditure [Noren et al 2009, 2012, 2013, Holt et al 2015, Noren et al 2017].	- The overall increase in energy expenditure is relatively low [Noren et al 2016b]. - The effect of reduced foraging is likely to have a greater impact on killer whales' energy balance [Williams et al 2006, Noren et al 2016b].
4. Reduced individual foraging success due to vessels may in turn result in reduced survival and fecundity that may result in population-level effects	- This topic has been studied in sperm whales [Farmer et al 2018 a, b] and studies in SRKW are ongoing - Individual whales with high energetic demands, such as lactating females and calves are likely the most susceptible to the consequences of reduced foraging [Farmer et al 2018 a, b].
5. Chinook prey abundance has a greater effect on orca population growth rates than vessel noise and physical disturbance, according to recent population viability analysis (PVA) models [Lacy et al 2017, Murray et al 2019].	- The combined effect of four key stressors—vessel noise and presence, vessel strikes, prey availability and contamination—largely accounted for the population trajectory of resident killer whales [Murray et al 2019]. - The combination of vessel disturbance and low prey availability is likely to enhance the negative effects [Ayres et al 2012]. - These models of multi-variable impacts have several caveats and limitations. *More in "Foraging Changes" below.*

6. Strike risk is not zero. The risk of mortality increases with speed.	- One PVA model estimates that there is one mortality every 10 years [Murray et al 2019]. - A vessel strike in 2016 resulted in the death of J34. Other SRKWs and Northern Resident killer whales (NRKWs) have collided with whale watch vessels and ferries in the past.
7. Data gaps include an understanding of the chronic effects of whale watching activities on SRKW foraging success under current management, and of the extent that reduced foraging success translates into the growth or decline for the SRKW population.	- Studies that have attempted to account for the overall effects of vessel noise on foraging [Lacy et al 2017, Tollit et al 2017, Murray et al 2019] are imprecise due to intrinsically high variability in such measurements and the assumptions necessary in their development and interpretation. *More in "Foraging Changes" below.*
Mitigation and Management	
8. While the presence of SRKW in inshore waters over recent years has been lower than historically observed, the evidence does not suggest basing management solely on recent levels of inshore habitat use.	- Changes in SRKW habitat use over recent years create uncertainty as to which areas of habitat are most important for successful foraging and other critical behaviors.
9. Observed habitat of SRKW suggests extending management actions to the entire SRKW home range, including the Salish Sea and outer coasts of Washington and southern Vancouver Island.	- Management actions for the Salish Sea are likely most beneficial to J-Pod, given this pod's consistently higher presence. - *Home range described in "Habitat Use" below*
10. There is insufficient evidence for a positive "sentinel" effect of commercial whale watching; this topic needs further study.	- A sentinel effect is defined as the presence of commercial whale watch vessels serving to alert and slow other vessels; a magnet effect is defined as the presence of the whale watch vessels drawing in additional vessels - A recent analysis of Soundwatch data [Hass 2020] did not support a sentinel effect, due to limitations in data collection and sample size. - No data were available for infraction rates when no commercial whale watch or Soundwatch vessels were present.
11. Slowing boats and decreasing time around whales, as well as increasing distance from whales, are considered the primary means to reduce noise levels.	- Setting noise threshold targets is not recommended due to the intrinsically high spatial and temporal variability of natural and anthropogenic underwater noise. - Local "Slow-Go" areas are worth consideration for the west coast of San Juan Island when SRKW are present. - New Canadian management measures are focusing whale watch tours away from targeting SRKW.
12. Reliable indicators for short-term adaptive management are not currently available. Time spent foraging, body condition, and other health indicators, such as physiological parameters, may be useful across longer time periods [National Academies 2017].	- Given that nearly all the threats to SRKW have the potential to affect an orca's body condition and health the best indicator may be behavior such as time spent foraging. - Metrics such as body condition, physiological changes, births, and population size have tradeoffs and limitations *More in "Management Challenges and Considerations" below.*

IV. Southern Resident Killer Whales in Washington State

The SRKW is one of three populations of resident killer whales in the eastern North Pacific. These orcas sit atop the food chain, serving as a sentinel for the health of the broader ecosystem. They also remain a cultural icon and economic driver for Washington State [U.S. Department of Commerce 2014; Van Deren et al 2019].

A Fragile Population

The SRKW population is believed to have been more than 200 animals in the 19th century, but modern impacts began to take their toll. Shootings and live captures for marine parks cut the SRKW population roughly in half during the 1960s and 1970s [Marine Mammal Commission 2020]. The first SRKW population census, conducted in the mid-1970s, counted just 66 orcas [Southern Resident Orca Task Force 2018]. After new restrictions on harming the whales and their prey were put in place, the population began to rebound.

Periods of growth continued until 1995, when the population peaked at 98 orcas before plummeting to 82 in 2004. That drop prompted the species' listing as an endangered species in Washington State in 2004 and under the U.S. Endangered Species Act in 2005. Canada had already designated the population as endangered under its Species at Risk Act in 2001. Over the last 15 years, growing concern for SRKW's survival spawned a series of committees, studies, publications, and increasingly stringent regulations.

Today, the SRKW population is down to just 73 orcas, its lowest level in four decades. Up to two-thirds of SRKW pregnancies from 2007 to 2014 failed [Wasser et al 2017]. None of the calves born between 2015 and 2018 survived. Until recently, failed pregnancies were not studied in SRKW, leaving no historical data for comparison.

Projections for the future of the population remain similarly pessimistic. In the past two decades, more male calves than female calves have been born, potentially reducing the population's reproductive potential even when calves survive [Marine Mammal Commission 2020]. Also, with so few individuals, not only do the whales have scarcer opportunities for reproduction but inbreeding is also more likely, which makes some individuals more susceptible to disease.

In 2008, the National Marine Fisheries Service set a recovery target of 2.3% SRKW population growth per year over 28 years to enable the removal of the SRKW from endangered status [National Marine Fisheries Service 2008]. The population has continued to face a host of threats that push them closer to extinction—from increased chemical pollution to decreased availability of prey. On this list of concerns, and the focus of this report, are underwater acoustics and vessel impacts.

There remains insufficient evidence to definitively say that vessel presence and noise is harming the SRKW population. There is, however, evidence of individual-level effects which could translate to population-level effects. At their current rate of reproduction, the potential biological removal (PBR) for the SRKW is one animal every seven years. If an impact is thought to potentially harm one animal, it follows that the population would be affected; a population is the sum of individuals [National Academies 2017]. U.S. legislation concurs that each whale is vital to protect, implying that any federal activities that could result in the loss of one individual are prohibited [National Oceanographic and Atmospheric Administration 2020]. Canadian regulations also suggest that if there is the potential for harm to an individual, then one can assume harm to the population [Fisheries and Oceans Canada 2018].

Habitat Use

The SRKW is composed of the J, K and L pods of extended family members. They travel in these pods from central Southeast Alaska to central California, with extended stays in the Salish Sea—the collective waters of the Puget Sound, Straits of Georgia and Juan de Fuca—and along the outer coasts of Washington and southern Vancouver Island.

Each pod has different patterns of habitat use [Hauser et al 2007]. J-pod's range, according to NOAA satellite tagging, is focused on the Salish Sea, with winter use of the northern Strait of Georgia. K and L pods range more widely. SRKW pods can change behavior quickly, fusing groups in certain geographic areas and splitting in others—these patterns of fusion/fission are observed by experienced vessel operators and researchers [Noren and Hauser 2016].

Between 1976 and 2014, a database collected by The Whale Museum in Friday Harbor, Wash., showed that sightings were concentrated in the central Salish Sea near the San Juan Islands during the summer months [Olson et al 2018]. Between 2009 and 2011, SRKW were detected acoustically at Swiftsure Bank, off the southwest coast of Vancouver Island, on 24% of recorded days [Riera et al 2019]. Detection rates averaged 42% between May and September. SRKW have also been observed in the lower Puget Sound area, which is outside the SRKW core summer habitat [Hauser et al. 2007, Noren & Hauser 2016].

In 2018, Soundwatch, a public outreach and boater education program operated by the Whale Museum in Friday Harbor, WA, observed SRKW on 34 of 65 monitoring days [Shedd et al 2018]. Even more recently, out of 74 days of monitoring in 2019, Soundwatch detected SRKW on 15 days and transients on 50 days [Shedd et al 2019]—a lower-than-typical presence from a historical perspective [Olson et al 2018]. While Salish Sea sightings are fewer in recent years, data continue to highlight the west side of San Juan Island, including Salmon Bank, as one key area of SRKW's preferred habitat. That is, the Salish Sea and San Juan Island region specifically have persisted as SRKW hotspots, particularly for foraging *(more in Key Foraging Areas below),* over the years.

Data suggest that SRKW currently spend a small, yet important, portion of their total time in the central Salish Sea, and that this time generally falls during the summer months. Restricting mitigation measures exclusively to that area, therefore, may not fully protect the future of the species in Washington State.

Key Foraging Areas

In pursuit of migrating salmon, research finds that SRKW frequent the southern region of Haro Strait, southwest of San Juan Island [Noren and Hauser 2016, Ashe et al 2010, Hanson et al 2013]. During the fall and winter, their foraging also trends further south in Puget Sound proper. These main foraging areas have persisted for several decades, as has their typical daily travel of 75 miles [Heimlich-Boran 1988; Noren & Hauser 2016; Ford et al 2017].

The literature suggests that the Strait of Juan de Fuca and waters off southwestern Vancouver Island have also become increasingly important for SRKW foraging. Generally, research indicates that SRKW foraging locations and patterns of habitat use are related to salmon abundance [Felleman et al 1991; McCluskey 2006]

Most published studies have relied on data collected over a decade ago, have not included data outside the SRKW core summer habitat near the San Juan Islands and, with the exception of one study [Hanson et al. 2010], based their conclusions on surface observations of SRKW behavior rather than verification of pursuit and capture of prey. Other areas such as southwestern Vancouver Island, including Swiftsure and La Perouse Bank, were proposed as habitats of special importance for the population [Ford et al 2017], and are now formally considered Canadian Critical Habitat. Additionally, a U.S. federal rule was recently proposed to revise the critical habitat designation for SRKW to include the Strait of Juan de Fuca and coastal waters along the U.S. west coast [National Oceanographic and Atmospheric Administration 2019a]. Ongoing and future studies of underwater acoustic data may further decipher current important regions of SRKW foraging.

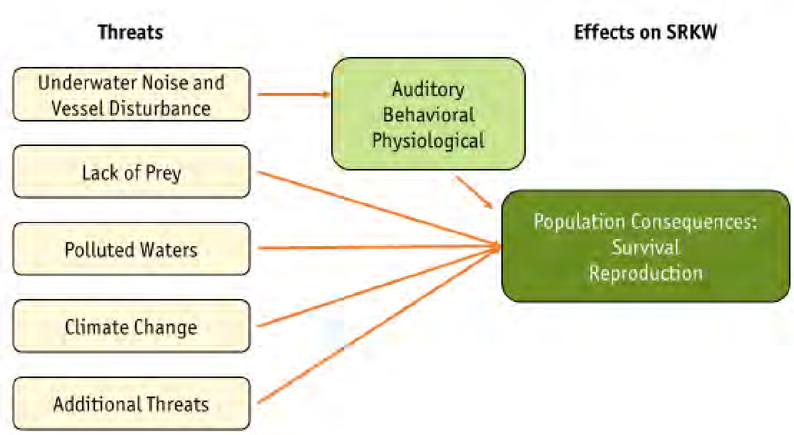
Since reduced foraging in the presence of vessels has been observed [Lusseau et al 2009; Christiansen et al 2013], protecting key foraging hotspots is valuable. Impact assessment studies suggest that reducing SRKW exposure to vessels when they forage will have beneficial effects for individuals, allowing them to continue supporting the population [Williams et al 2006; Lusseau et al 2009; Ayres et al 2012]. Although sightings of SRKW vary month-by-month, the whales have a consistent need to forage and thus need season-round protection of key foraging habitat.

Still, as prey availability changes, whale distribution in their habitat is expected to change. Therefore, adaptive management is critical for linking regulations to observed animal distributions rather than to a small geographic area. Adaptive management will allow vessel spatial restrictions to be reviewed regularly to accommodate any documented or observed changes in SRKW foraging patterns.

Key Stressors

The SRKW population faces a number of threats that impact its food supply, foraging ability, habitat, and communication. As depicted in Figure 1, these stressors—primarily vessel noise, vessel presence, limited prey availability, and polluted waters—can be cumulative as well as interact indirectly through the physiological changes a single stressor can cause to a whale [National Academies 2017]. Each of the threats alone are also complex and carry uncertainty due to ongoing difficulties in observing and quantifying effects on cetaceans, as well as the recovery challenges inherent with a small population.

Figure 1. A diagram representing the basic mechanisms through which different stressors impact the SRKW population. Stressors include underwater noise and vessel disturbance, lack of prey, pollution, and climate change. These stressors interact to produce cumulative effects on SRKW survival and reproduction. [National Academies 2017; Southern Resident Orca Task Force 2018].



Vessel noise and presence

Killer whales use sound to navigate, communicate, and locate prey via echolocation. Elevated noise from vessel traffic can disrupt all those activities. Whales are generally acclimated to constant steady sounds like rain, wind, or crashing waves. Because SRKW spend a lot of time in the quieter waters of sheltered passages, they may be less acclimated than species that primarily reside in the open ocean. Still, while constant noise might trigger effects, variations in noise are thought to generate the most significant behavioral responses.

Vessel noise in the Salish Sea has significantly raised the background broadband noise levels [Veirs & Veirs 2005]. This underwater noise has been shown to be in the frequency range that SRKW use for communication and echolocation [Au et al 2004, Veirs et al 2016].

Vessel noise generation varies with vessel type and size. The principal sources are propeller cavitation, which is a function of blade rotation and hence vessel speed, and engine machinery harmonics, which radiate from the hull of the vessel [Carey & Evans 2011]. Echo sounders also contribute to vessel noise [Phillips & Kendrik 2020 (VARD), Deng et al 2014]. Importantly, how this underwater sound propagates depends on water depth, weather, tidal conditions, and the composition of the seabed. A muddy bottom, for example, will attenuate the sound more than a rocky bottom.

The mere presence of a vessel, even a quiet one such as a kayak, can also affect SRKWs [Williams et al 2010]. Vessel strikes remain a further threat to SRKWs, although just how often they occur is unclear [National Oceanographic and Atmospheric Administration 2020, Raverty et al in review]. One model estimates that there is one mortality every 10 years [Murray et al 2019].

While underwater noise and vessel disturbance have arguably the most potential to be readily addressed via regulations, other factors pose threats to the SRKW population.

Limited prey availability

The core of the SRKW's diet is Chinook salmon, along with smaller amounts of Coho, chum and steelhead. An adult male orca requires approximately 325 pounds of Chinook to meet its daily prey energy requirements [Southern Resident Orca Task Force 2018]. A reduction in prey availability likely makes it difficult for the SRKW to meet their daily prey requirements.

Several runs of Chinook salmon are listed as threatened or endangered under the Endangered Species Act. Scientists have reported ongoing changes in both the number and size of the returning salmon [Ford et al 2010, Ward et al 2009, Williams et al 2011]. Exacerbating the impacts of reduced prey abundance for SRKW, research suggests that the impact of boat presence on the orcas is greater during a poor salmon year than when prey is ample [Ayres et al 2012].

Human population growth has directly and indirectly impacted salmon populations via the loss, damage, and fragmentation of juvenile salmon habitats, as well as adult spawning habitat. Implicated human impacts include development, transportation, agriculture, logging, mining, dams and other hydrologic alterations, contaminated stormwater, and groundwater withdrawals. Vessel disturbance may also alter salmon behavior.

Climate change exacerbates many of the threats to SRKWs including stresses on salmon populations. Warmer stream temperatures, lower summer stream flows, heavier winter rainstorms, warmer ocean temperatures and sea-level rise are all predicted to affect the quantity of prey for the orcas [Southern Resident Orca Task Force 2018].

Higher prey availability in key areas likely makes it easier for SRKW to handle stressors. However, the science shows that SRKW reduce foraging behavior in the presence of vessels, regardless of prey availability. That is, SRKW need not only a sufficient fish population to forage but also opportunities to forage undisturbed.

Polluted waters

Both SRKW and their prey are exposed to a cocktail of pollutants in the marine environment, particularly in the Salish Sea. Many of the pollutants persist in the environment, bioaccumulate through the food web and are poorly metabolized. Orcas are long-lived and sit at the top of their food web. Consequently, individuals accumulate high levels of pollutants over their lifetime, which makes them especially vulnerable to the deleterious effects of these compounds [Krahn et al 2007].

Exposure to toxins, whether directly or indirectly through their diet, can reduce immunity and cause reproductive stress to the orcas. Further, pollutants may decrease prey abundance as exposed salmon, too, may become more susceptible to disease and reproductive stress. A Southern Resident Orca Task Force working group identified a list of primary contaminants of concern including polychlorinated biphenyl (PCB), polybrominated diphenyl ether (PBDE), dichloro-diphenyl-trichloroethane (DDT) and polycyclic aromatic hydrocarbons (PAHs), along with contaminants of emerging concern such as phthalates, bisphenols and pharmaceuticals [Southern Resident Orca Task Force 2018]. Further pollution threats to the SRKW include vessel exhaust [Lachmuth et al 2011, Lundin et al 2018], and oil spills.

Other stressors include viruses such as the emerging cetacean morbillivirus [National Academies 2017].

V. Vessel Behavior and SRKW Exposure

Various types of vessels frequent the waters of the Salish Sea including commercial boats, research boats, barges, ferries, military vessels, and private watercraft. The scope of this summary is limited to smaller vessels, particularly whale watching boats.

The level of vessel exposure faced by orcas depends on numerous factors: the density, distance, and direction of the boats, as well as the boats' speed and other actions, including operator behaviors. Environmental factors such as the seabed substrate and proximity to shoreline can also influence vessel sound transmission.

State and federal regulations for small vessels interacting with orca have changed substantially over the last decade. For example, 2008 Washington State regulations limited the approach distance to 100 yards from the whales, and were updated in 2012 to 200 yards away and 400 yards out of the whales' path, and in 2019 to 300 yards away and 400 yards out of the path in front and behind the whales [SB 5577]. In parallel, NOAA in 2011 issued regulations limiting vessel traffic within 200 yards of the whales and 400 yards of the whales' path [National Oceanographic and Atmospheric Administration 2019]. Studies in the last decade have been conducted under different regulatory conditions.

Vessel Counts

The number of active commercial whale watching vessels operating in Washington State increased from 63 in 1999 to 106 in 2018, and then dropped slightly to 100 in 2019, according to the Soundwatch Boater Education Program by The Whale Museum. The number of people kayaking near whales also increased between 2004 and 2015, before dropping steadily over the last five years [Seely et al 2017, Soundwatch 2018, Soundwatch 2019].

One limitation of the existing research is that, in some cases, data is only available for pods that are found by research vessels or ecotour vessels. Additionally, whale watching vessels are just one of many types of boats on Washington State waters that affect SRKW, and likely represent a small fraction of the underwater acoustic and vessel disturbances they encounter. For example, recreational vessels make up a large proportion of the vessels near whales [Soundwatch 2019].

While Soundwatch data provides vessel counts by type—recreational versus commercial whale-watching vessel—it does not differentiate the sound coming from each type of vessel. The number of vessel incidents or violations of regulations and guidelines has fluctuated in recent years, ranging from a low of 398 in 1998 to a high of 2621 in 2012. Incidents and violations dropped to 1,117 in 2018 and further to 749 in 2019 [Seely et al 2017, Soundwatch 2018, Soundwatch 2019]. There are no published data on the behavior of recreational vessels with or without the presence of whale watching boats. However, a 2018 Soundwatch report did find a reduction in regulation incidents with the presence of a law enforcement vessel [Soundwatch 2018].

Studies of orcas and other cetaceans find that the effect of vessel presence on animals increases with vessel numbers, particularly for three or more vessels [Williams et al 2002, Williams et al 2009, Williams and Ashe 2007]. However, the literature has not measured differential impacts for fewer than three vessels. The practice of leapfrogging, in which the operator places the boat in the path of the whale, also increases severity of behavioral responses [Williams et al 2002].

Distance from Whales

The general increase in vessels over the last two decades has translated into an increase in traffic within 1000 meters around SRKW. However, researchers also measured fewer vessels within 100 meters in 2018 and 2019. [Vancouver Fraser Port Authority 2019 (ECHO)].

Various studies have defined the “vicinity of SRKW” differently. Most studies report distances as rings emanating from whales. Soundwatch counts vessels within 1000 meters, for example, while other studies include vessel counts up to 400 meters and 1000 meters from SRKW [Holt et al 2009, Lusseau et al 2009, Soundwatch 2019]. Given current data collection protocols, 1000 meters can be used as a rough estimate of “vicinity.” Still, research suggests that vessel radiated noise—which depends on a vessel’s size, speed, and propulsion system, as well as environmental factors—can be detectable by an orca beyond this distance [Erbe 2002].

Distance is further related to the level of impact to the whales, with larger disturbance effects occurring the closer vessels are to whales. Behavioral response data suggests that an orca shows behavioral responses when a vessel is within 400 meters [Lusseau et al 2009, Noren et al 2009, Williams et al 2009], and orcas increase their call amplitude (or volume) with increasing background noise, which correlates with the number of vessels within 1000 meters [Holt et al 2008, Holt et al 2009]. More research is needed to define the distance from SRKW that boats can travel without negative effects.

Many older studies report orca behavioral changes within certain distances, including distances that are closer than the current regulations allow, and with other vessel behaviors that have changed over time. As some data were collected at greater distances than guidelines or regulations at the time, some of that information could still be valid for interpretation. For example, a 2009 study showed reduced foraging when vessels were within 400 meters of whales in any direction or orientation, not only the front and back [Lusseau et al 2009]. Still, predictions of cumulative effects that are based on outdated proximity regulations should be viewed with caution, as recent restrictions are predicted to reduce noise levels received by killer whales [Tollit et al 2017].

In interpreting the data, it is important to differentiate studies that explored and described patterns in whale and vessel use of space from studies that aimed to unravel the mechanistic relationships between human exposure and whale response.

Vessel Technologies

Improved vessel technologies could reduce noise in the long term. Electrification of boats, which Washington State Ferries is currently pursuing for their fleet, could reduce some of the acoustic disruption. A newly published case study finds reduced noise from a solar electric ferry in the Swan River in Western Australia [Parsons et al 2020]. Given the many environmental factors that affect noise propagation, specific study is needed in the Salish Sea.

Importantly, electrification would not eliminate the main source of vessel noise: cavitation from propellers [Aktas et al 2016]. Other technologies in development could result in boats that reduce cavitation and vibration. Alternative propulsion mechanisms such as air-jets could increase broad-spectrum underwater noise.

Sentinel or Magnet?

There is insufficient scientific evidence to support a sentinel effect, in which the presence of commercial whale watch vessels and active outreach by operators serves to alert and slow other vessels, or a magnet effect, in which the presence of the whale watch vessels draws in additional vessels.

Little published empirical evidence exists for potential sentinel or magnet effects of whale watching vessels. A recent analysis [Hass 2020] revealed complexity and uncertainty in the relationship between infractions and the number of vessels with whale flags, which could be due to a limited sample size. No data was available for infraction rates when no commercial whale watch or Soundwatch vessels were present. The committee suggests additional analysis of Soundwatch data.

Caution must be used when assuming a sentinel effect exists without sufficient evidence. As vessel presence is currently known to have behavioral and physiological effects on whales, the precautionary principle leads the committee to presume that there is no sentinel effect until otherwise demonstrated.

VI. Vessel Effects on Southern Resident Killer Whales

NOTE: The committee has excluded multiple studies on responses to specific sound types such as pile-driving and naval sonar that are not relevant to the scope of this review.

There is a dearth of studies that address the direct impacts of the presence and acoustic disturbance of vessels on the SRKW population. However, the research that does exist on these whales, combined with evidence of noise impacts on populations of other marine and terrestrial taxa—such as Northern Resident killer whales and dolphins, as well as birds and chinchillas—suggests a range of potential behavioral and physiological consequences.

These effects are not necessarily mutually exclusive. A behavioral response might occur to mitigate an auditory effect, for example, such as when a person moves away from a loudspeaker at a concert to avoid temporary hearing loss. An impact may also vary based on concurrent threats to the population, as well as factors such as the whale's current body condition and net energy intake or the location of vessel traffic relative to Chinook salmon migration.

Behavioral Changes

When in close proximity to boats, SRKW appear to increase surface-active behaviors [Noren et al 2009], raise call amplitude [Holt et al 2009], modify respiration rate, alter surfacing patterns, change swim patterns, and increase swim speed [Williams et al 2009]. SRKW and Northern Resident killer whales (NRKW) also reduce their foraging behavior when in close proximity to boats [Williams et al 2006, Lusseau et al 2007, Lusseau et al 2009, Williams et al 2016].

While these studies were conducted under older federal marine mammal viewing regulations, two of the studies [Lusseau et al 2009, Williams et al 2009] assessed impacts of vessels at distances of 400 meters and 1000 meters and could therefore provide relevant data applicable to today's regulations.

Silent boats, too, may elicit avoidance responses. The presence of kayaks appears to increase traveling behavior in killer whales [Williams et al 2011]. Other studies add further evidence that vessel presence is a concern [Lusseau et al 2006, Pirotta et al 2015].

The greater the number of boats, the greater the radiated noise levels around killer whales and the greater the behavioral impacts, according to several studies. A study of NRKWs found that the animals changed their activity state when in the presence of more than three boats [Williams et al 2007]. Vessel counts up to a distance of 1000 meters appear to correlate with ambient noise levels, and higher ambient noise levels appear to correlate with higher SRKW call amplitudes [Holt et al 2009]. While methodological constraints limit the interpretation of the results and conclusions, research suggests that the cumulative effect of large numbers of vessels have contributed to the physiological stress in SRKWs, particularly during years of relatively low Fraser River Chinook abundance [Ayres et al 2012].

Vessel size may also matter. Larger vessels are less likely than small vessels to behave unpredictably around the whales, and tend to have lower-frequency noise features that are less likely to overlap with SRKW vocalizations [Veirs et al 2016].

The research on the intensity of vessel noise is less clear. The committee is also not aware of further studies that tease out vessel noise from vessel presence or report on how different numbers of vessels within the range of distances may impact killer whale behavior.

Foraging Changes

Despite the potential for low prey availability to be an impactful SRKW stressor, alleviating impacts on foraging behavior would be critical for maximizing the foraging opportunities of these whales. Some studies predict that SRKW lose substantial foraging time due to vessel presence and vessel noise [Tollit et al 2017, Joy et al 2019, Lacy et al 2019, Murray et al 2019]. However, the committee stresses some significant limitations with these studies and does not recommend relying on their results for management decisions.

For example, Lacy et al 2017 uses a crude approach to estimate potential noise effects in the baseline model, and the effects on foraging of close boat approaches were extrapolated to occur year-round. Tollit et al 2017 is unpublished and uses multiple assumptions to estimate potential noise effects. The authors highlight high uncertainty, particularly in converting the range of reductions in clicks through masking to a unifying lost foraging time metric. More research is needed to understand the extent of potential foraging losses during close approaches by vessels.

Reduced foraging, lower food availability, evasive behaviors and the production of louder calls all have the potential to impact a whale’s energy balance. SRKWs may increase energy expenditure by performing surface-active behaviors in the presence of boats [Noren et al 2009, Noren et al 2012]. Though SRKW switch activity states away from foraging when disturbed [Lusseau et al 2009], they do not necessarily depart the area entirely. Further, if boats follow SRKW after they switch behavior to travel, the SRKW behavior change would not alleviate their exposure to vessels.

Maximum dive depth [Baird et al 2005] and unpublished data on vocalization rate [Thornton et al 2019] suggest that foraging typically occurs more during daytime hours, when whale watching vessels are most likely to be present. However, deep dives don't necessarily result in prey capture [Tennessen et al 2019]. A current NOAA digital acoustic recording tag (DTAG) study is collecting data to understand foraging behavior and activity patterns throughout both day and night. However, many foraging factors are unknown and minimal research addresses this question.

VII. Evidence for Mitigation, Management, and Education

NOTE: The committee will be preparing, separately, recommendations for adaptive management of regulations. This section serves to highlight the science of mitigation and management, as well as potential education strategies.

Regulations for whale watching vessels have evolved in recent years, as has the ecology of the whales and their prey. Newer and more restrictive state regulations on distance from SRKWs and speed have been in place since 2019.

The debate continues over the direction of future regulations. Scientists and policymakers note two potential roads of management: micromanaging each interaction, which involves substantial policing, or defining every interaction as an opportunity to disturb a whale and taking a precautionary management approach.

In general, an adaptive management plan needs to include all relevant factors that could change and/or be manipulated based on a set of testable hypotheses. Adaptive management requires monitoring what is being managed (vessel interactions), the response (such as population), and other interacting and cumulative factors.

- **Quota systems:**
  Regulating the density of whale watching vessels around whales is one way to reduce SRKW vessel exposure. This approach could allow industry to develop new business models to maintain operations. On the other hand, a licensing program that limits the duration and number of vessels near SRKWs and which does not account for the entire core habitat could distribute the effects of noise and disturbance across a greater number of orca groups or individuals. Such unknowns lend themselves to ongoing monitoring and adaptive management.

- **Special protections:**
  Programs could grant additional protections for specific demographic groups of orcas that are most likely to be negatively affected by vessel disturbance. For example, in Australia, extra protective rules apply to mothers and calves to protect lactating mothers with high energetic demands [Australian National Guidelines for Whale and Dolphin Watching 2017].

- **Enforcement of current regulations:**
  New regulations issued by Washington State in 2019 require boats to stay 300 yards from SRKW on either side, as well as 400 yards in front and behind the orcas' path. Regulations also require

disengaging engines if whales appear within 300 yards of SRKWs. Not enough time has passed to evaluate the impacts of the latest regulations.

However, even if the restrictions prove to protect SRKW, they are only as effective as they are adhered to. Optimizing compliance may entail enforcement boats. The 2018 Soundwatch report found a reduction in regulation incidents with the presence of a law enforcement vessel [Soundwatch 2018]. Another option is the presence of a trained observer/monitor on whale watch boats to monitor the boat's interactions with whales and also report compliance by recreational vessels in the vicinity.

- **Exclusion zones:**
  Boats could be altogether banned from entering areas where SRKW are currently known to spend substantial time foraging and instead limited to areas through which whales generally only travel. In addition, if an exclusion zone is implemented for whale watching vessels, it could readily become an exclusion zone for other vessels in the future. In addition to conferring protection, exclusion zones could also offer an experimental control area for research studies.

  The Salish Sea and San Juan Island region specifically have persisted as SRKW hotspots over the decades [Hauser et al 2007, Noren & Hauser 2016]. However, given the documented changes in SRKW use of the San Juan Islands area in recent years, no-go areas may become outdated if the zones are spatially fixed for a period of years. For example, SRKW have reduced use of the San Juan Island foraging area in recent years compared to historical records [Soundwatch 2019]. A more flexible approach could be creating temporary exclusion zones, where exclusions are implemented adaptively, reviewed periodically, and lifted after data show a period of no SRKW presence. The areas might also be closed only when SRKW are in the area.

- **Further speed restrictions:**
  Noise levels have been found to increase with speed [Wladichuk et al 2018]. Not surprisingly, speed reductions appear to reduce acoustic disturbances for whales. A speed reduction from between 5 and 6 knots down to between 0 and 2 knots reduced sound levels that whales received by an average of 4 to 5 dB, according to a study using DTAGs [Houghton et al 2015]. Another study found similar results using an expanded DTAG dataset [Holt et al 2017].

  Vessels operating at moderate-to-high speeds produce greater masking effects than lower speeds [Houghton et al 2015, Holt et al 2017]. Researchers have found large-scale reductions in noise levels when comparing speeds of greater than 15 knots to speeds below 7 knots, across a variety of boat types [Wladichuk et al 2018]. A voluntary large commercial vessel slowdown trial in the Salish Sea—down to 11 knots—showed reduced underwater noise in the slowdown area. The trial predicted an overall 22% reduction in 'potential lost foraging time' for SRKW, with 40% reductions predicted under 100% participation scenarios [Joy et al 2019]. Source level studies also suggest a stronger speed-sound correlation in the SRKW echolocation band than in lower-frequency bands, which is likely due to propeller cavitation noise rather than engine noise.

  However, while the total sound energy emitted is lower for slower vessels, the overall impacts are not necessarily clear. While faster speeds increase the intensity of noise and the risk of vessel strikes, slower speeds expose orcas to noise for longer periods of time and potentially risk longer masking periods. A 'slow-go' or slowdown approach could have similar noise reduction potential to an exclusion zone but may increase the amount of time SRKW spend with boats.

- **Noise thresholds:**
  A number of problems make specifying a noise threshold limit unrealistic and unenforceable. For one, the threshold would need specificity to both the SRKW hearing frequency range and the whales' higher frequencies of echolocation. Such a large bandwidth poses challenges to acoustic sampling. The threshold would also need specificity for measurement depths as SRKW use the entire water column acoustically when foraging [Holt et al 2019]. Further, statistically reliable estimates of noise require continuous measurement on the scale of days, not hours, while mammalian auditory processing requires shorter averaging times [Erbe et al 2016, Section 3.3]. Short time estimates will be encumbered by huge variability.

  One study indicated 50% of behavioral changes of NRKW at broadband received levels of 130 dB [Williams et al 2014b], while broadband received levels as low as 111 dB were used in another noise effects study [Tollit et al 2017]. The maximum sustainable level of vessel noise and disturbance for the SRKW population is uncertain, especially because the maximum disturbance is contextual and dependent on ecological factors. For example, SRKW can better handle intermittent disturbance when there is an abundance of food (i.e., compensatory abilities are better in periods of abundance). Some estimates can be made by reviewing population consequences of disturbance (PCOD) models.

  Taken together, evidence suggests that while a noise limit may not be a useful enforcement monitoring or regulatory target, lowering noise levels would be beneficial to the whales. Noise levels could be lowered by the above-mentioned actions, such as reducing the time with whales, the number of viewing vessels and their speed, as well as regulating vessel approach and departure practices that increase distance from whales.

- **Alerts and education by whale watch fleet**:
  The whale watch fleet has the potential to help mitigate the disturbances of other vessels on the water. Whale watching vessels can actively report harassment incidents and alert other vessels to orca presence via the Whale Report Alert System, an app for reporting real-time sightings that triggers warnings for commercial maritime operators such as ferries, ships and tugboats. A reporting protocol could also be created through an automated hotline such as the one managed by NOAA for North Atlantic Right Whales.

  Data to be reported would include whale identification (including whether it is an adult or calf), location of the whale and how long it was in the area, whether the whale has injuries or other unusual characteristics, whether there are other boats in the area, and how long each boat is present. Ideally, reporting would be done by trained naturalists who could also identify the pod and whale activity state; the presence of trained naturalists is a requirement in management schema in other localities.

  However, it is not clear whether whale watching vessels will actually act as a magnet—or as a sentinel—for other boats that want to observe whales. Limited data prevent the committee from making any confident statements on the sentinel or magnet effect of these vessels.

  Robust evidence would also be needed to support the claim that SRKW education provided by commercial whale watching would lead to shifts in public attitudes or behaviors that support salmon habitat restoration and other conservation efforts.

  Requiring an Automatic Identification System (AIS) on whale watch boats could produce the data needed for answering many scientific questions about spatial patterns in vessel locations and densities. AIS would also likely increase data quality and reduce the burden of reporting SRKW sightings. These characteristics could enhance conservation efforts by shedding light on vessel density around whales and whale movement patterns.

- **Further distance restrictions:**
  Some older studies report behavioral changes within distances beyond the current restrictions, suggesting likely impacts to SRKWs even by regulation-abiding boats. Canadian regulators have taken a precautionary approach in which recreational boaters must stay 400 meters away from all killer whales, while ecotour companies cannot approach any SRKW pods but can approach transients at a 200-meter distance.

- **Noise reduction technologies**:
  Seeking strategies to reduce noise emitted by boats could help protect the SRKW population and be beneficial to other species. While not necessarily a short-term tactic, improved vessel technologies could reduce noise in the long-term. Electrification of boats, which Washington State Ferries is currently pursuing for its fleet, could reduce some of the acoustic disruption. Still, electrification will not eliminate the need for propellers; cavitation from propellers is the main source of vessel noise. Other technologies in development could result in stealthier boats that reduce cavitation and vibration.

- **Improving boater behaviors:**
  Licensure could require education on a variety of behaviors that may reduce SRKW exposures, such as staying downwind from the whales to reduce vessel exhaust, turning off echosounders when in the vicinity of whales, and reducing changes in speed, starts, stops, and gear shifts. Permits could be used to require education to increase regulation compliance.

  Licensed operators could also be asked to record details of orca encounters and contact recreational vessels via the radio to inform them of SRKW presence and explain distance and speed regulations. If regulations were to mandate that whale watch vessel operators serve this role, the change could increase the scope for a sentinel effect. Still, the magnitude of this effect, and therefore its effectiveness, would remain largely unknown. Such a requirement could also create issues such as a perceived conflict of interest or a lack of authority.

- **Population targets:**
  While population number is a clear and easy measurement, the current ecosystem's carrying capacity for SRKW is less obvious—especially when considering the potential impacts of climate change. Both the carrying capacity and the minimum viable population number are important elements of any target-setting process in an adaptive management plan.

  Demographic issues with a small population size also make recovery continually more challenging. Even if vessel interactions are at a tolerable level, the population may not be able to produce a calf for a variety of other reasons. Population count is an integrated target that relies on many other factors – that is, while management of vessel interactions may be successful, the SRKW population may take a very long time to reach, or fail to reach, a particular size.

Some management regimes in other areas, which incorporate combinations of the above, include:

- In Saguenay-St. Lawrence Marine Park (Québec, CA), regulations were developed in collaboration with users that include a maximum navigation speed in the park, lower speeds when marine mammals are present, a minimum distance from marine mammals, maximum times that boats can spend in an observation zone, and temporary exclusion areas. Permits are required for activities in the park, the number of permits is capped, and whale watch operators are required to go through training on behaviors to avoid disturbing blue and beluga whales. Further, the program includes reporting requirements for whale watch operators as well as education requirements for passengers [Parc marin du Saguenay-Saint-Laurent].

- Pelagos Sanctuary in the Ligurian Sea developed a management plan and requirements for conduct by tour operators. Components of the effort include a 300-meter vigilance zone around whales where only one boat is allowed at a time, limiting observation time to half an hour per boat and 15 minutes if other boats are waiting, and requirements for switching off sounders and sonar [Pelagos Sanctuary].
- In Doubtful Sound, New Zealand, the NZ Department of Conservation has worked in collaboration with the tourism industry to introduce interaction avoidance (no-go zones) in critical areas for a population of bottlenose dolphins listed as critically endangered [Lusseau et al 2004]. This approach has resulted in significant reductions in the time dolphins spent with boats and in the length of interactions [Guerra and Dawson 2016].

VIII. Management Challenges and Considerations; Additional Data Needed

Before SRKW population recovery strategies can be optimally implemented, there are a number of considerations to make, limitations to overcome and knowledge gaps to fill.

- **Monitoring effectiveness:** Management metrics are most useful when they are clear, simple, explicit, easy to enforce and associated with a specific assessable goal [Ferrara et al 2017]. For example, the number of boats or their speed is easier to regulate than a vessel's noise output.

- **Improved understanding of noise metrics:** Reported measurements of underwater ship and whale watch vessel noise are often of little comparative value because such data can be significantly influenced by the specific underwater environment where the measurements were made [McKenna et al 2012, Simard & Roy 2016, Gassman et al 2017]. Recent underwater radiated sound level data do not fall into this category [Wladichuk et al 2018, Wladichuk et al 2019].

- **Finding markers of success for SRKW***:* It will be difficult to link population changes to management actions, especially in the short-term (*more in Population Targets above)*. Table 2 outlines the benefits and drawbacks of several possible metrics.

  Given the unlikely event of any significant population growth for SRKW in the next two years, short-term behavioral changes, such as habitat use as measured by SRKW distribution, and foraging frequency and success, are more direct measures of SRKW response to changes in vessel regulations. Daily foraging rates and the daily number of successful foraging events, based on tag data, could serve as proxies for orca energy balance. However, behavioral metrics can be time intensive and expensive to measure and can be confounded by prey availability.

  Body condition, particularly calf condition, has been used as a metric to reflect individual health and population growth rate [National Academies 2017]. However, using this metric requires a longer timescale to see impacts, and other risk factors can potentially impact body condition [Riera et al 2019]. Further, current body condition metrics such as the eye patch ratio and the head width to dorsal fin-to-rostrum length ratio, naturally change with growth, age, and reproductive status [Fearnbach 2018; Fearnbach 2019; Noren et al 2019]; additional research is needed to determine "healthy" values of these indices for specific age and sex classes. Consequently, specifying body condition values that correspond to good and poor health is challenging.

  Given the complexity and interconnectivity of risk factors, it would also be challenging to relate positive changes in body condition, reproductive success, calf survival, or population growth rate solely to vessel regulations.

Table 2. Benefits and drawbacks of metrics for measuring successful SRKW population recovery from management of vessels.

Metric	Length	Benefits	Limitations
Behavior, including foraging rates and success, habitat use, etc.	Short-term (immediate)	Only metric that directly measures whale response to vessel regulation changes	Intensive and can be expensive to measure Can be confounded by prey availability
Population size or percent increase	Long-term (5+ years)	Clear and easy measurement Direct link to management goal of population recovery	Needs to incorporate carrying capacity and minimum viable population Affected by multiple factors beyond vessel noise and disturbance
Body condition, particularly for juveniles or reproductive female	Medium-term (weeks to months, buffered by blubber layer)	Reflects individual health Relatively simple to measure and compare over time	Changes with growth, age, and reproductive status; additional research needed to determine "healthy" values Affected by multiple factors beyond vessel noise and disturbance
Births or calf survival	Medium-term (years)	Indicates population growth in shorter-term	Challenge to measure, depending on aerial photogrammetry effort and SRKW habitat use patterns Affected by multiple factors beyond vessel noise and disturbance
Physiology changes: stress hormone levels, bioenergetics, etc.	Short-term (possibly days, dependent on sampling)	Reflects individual health	Changes with other physiological processes such as pregnancy Affected by multiple factors beyond vessel noise and disturbance
Boater behavior, including: # of boats near whales, time with whales, etc.	Short-term (immediate)	Measures adherence to management	Doesn't measure whale response/recovery

- **Building SRKW-specific research:** Few studies have looked directly at noise and disturbance effects on SRKWs, including their echolocation clicks, the degree of impact from sound exposure levels versus sound type variation, and the physical presence of boats. It remains unclear what an acceptable level of sound might be for this population.

- **Understanding boat density***:* Some data exist on the density and distribution of boats [Soundwatch 2018; Soundwatch 2019], but boat density around whales, including in core foraging areas, is not static. The committee is aware that local researchers have unanalyzed data on the density and distribution of boats, particularly in core foraging areas, but no analyses have been published yet. The committee is also aware that San Juan County is currently teaming up with Oceans Initiative for a study which will add to the understanding of how group size and group dispersion has varied over the last 18 years and how Chinook salmon abundance may play a role in determining the grouping behavior of SRKW.

- **Considering the whole context:** Using only sound levels as proxies for vessel impacts and ignoring the total presence, proximity, and relative orientation and movement of disturbances relative to the orcas will fall short of fully evaluating impacts from many sources and achieving science-based conservation.

- **Disentangling factors to measure impacts:** Quantifying and observing cumulative effects on cetaceans is difficult and currently not possible, especially in light of changing baselines (e.g., regulations, ecologies of prey and whales). For example, vessels and noise generally occur together. No study of killer whales has teased apart vessel presence from noise generated by vessels, with the exception of the observational study on kayaks. A study is needed in which vessel noise is broadcasted and responses are measured in the absence of any physical vessel.

- **Keeping up with evolving regulations and behavior:** With adaptive management over the last 20 years, the data used in many studies has become quickly outdated. New data is necessary to determine the level of disturbance under current management.

  Adaptive management plans can stipulate changes in the plan based on changes in population status over time. One example is the IWC Revised Management Procedure (https://iwc.int/rmp), which introduced a ban on extractive activities until populations recover.

- **Sentinel effect:** In order to determine a sentinel or magnet effect of commercial whale watch vessels, studies would need to be conducted to assess if or how observed, reported, or enforced infractions change with a change in the number of whale watch vessels present. In order to establish this connection, additional research would need to be conducted with:
  - At least one and preferably more seasons of Soundwatch observations;
  - In addition to observations, a controlled study with a sufficiently large sample size of randomized applications of interactions with recreational vessels, tracked over a season or more;
  - Combined land-based observation (which biases sampling in the landscape of whale presence) and boat-based observation (which may bias boater behavior);
  - Measurement of claims such as reduced recreational vessel interaction and speed;
  - Encounters with transient killer whales would be appropriate for this type of study because boater behavior (not whales) would be the subject of the study.

- **Foraging areas:** A clear understanding of where SRKW forage successfully will be important. In addition, there are some data on foraging success and location from studies using DTAG and post-foraging scale-collection; however, it could be helpful to generate bounded monthly or seasonal use estimates of a large sub-area of the SRKW range by pooling acoustic, sighting, and other data. That data could be matched with an estimate of boat interaction in the sub-area.

- **Defining management values:** Research is needed to define how much interactions should be reduced and, therefore, the SRKW maximum sustainable tourism yield. The approach used could be similar to the Potential Biological Removal (PBR) estimation procedure of bycatch conservation strategies [National Oceanographic and Atmospheric Administration 2019].

- **Learning from current events:** It is not clear whether the COVID-19 pandemic has decreased ocean noise and thus creates an opportunity for study. Anecdotal evidence suggests recreational and commercial vessel traffic has shifted (with declines in cruise ship landings, for example), but not declined overall.

IX. Bibliography

Full literature list in Appendix.

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Appendix – Bibliography of Key Research about Underwater Noise and Vessel Disturbance

Objective

The purpose of this document is to track literature that the WSAS Underwater Acoustics and Disturbance Committee may consider in reviewing the best available science on underwater acoustics and disturbance of Southern Resident Killer Whales (SRKW). by small vessels. The committee is reviewing literature from species beyond *Orinus orca* due to the dearth of information on SRKW directly. The committee has excluded multiple studies on responses to specific sound types such as pile-driving and naval sonar that are not relevant to the scope of this review. This list of literature reflects suggestions made by scientists participating in the April 27, 2020 workshop and stakeholders participating in the May 6, 2020 workshop.

Topics

- Comparative connection of taxa
  - Patterns of behavior and abandonment in other cetaceans
  - Stress physiology
- Effects of:
  - Physical disturbance of vessels
  - Underwater noise
  - Echo sounders
  - Acute vs Chronic exposure
  - Numbers of vessels and amount of time spent
  - Interacting stressors – relative effects
- Boat density and distribution – Small vessels, Whale watch vessels
  - Especially around San Juans
- Vessel noise generation – cavitation, technology
- Ocean ambient noise; masking
- Sound propagation
- Marine mammal hearing
- Types of effects
  - Physiology
  - Behavior
- Whale watch customers
  - What customers want (outreach, closeness to whales, # of whales)
  - Demographics
- Whale watching
  - Effects on conservation
  - Best practices for conservation
  - Effects of public perception
  - Sentinel effect
- Adaptive management of regulations

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